TP 4238E

REPORT ON FOUR VISITS TO MARINE SHIP-HANDLING SIMULATORS IN THE NETHERLANDS AND THE U.K.

for

Transport Canada
Transportation Development Centre

Library and Information Centre/
Centre de Documentation (GSLA)
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MAY 31 1983
Transport Canada / Transports Canada

by

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Toronto, Ontario

December 1982

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
4238E	4792	

4. Title and Subtitle	5. Report Date
"Report on Four Visits to Marine Ship - Handling Simulators in the Netherlands and the U.K."	December 1982
	6. Performing Organization Report No. MMS-4
7. Author(s) John W. Senders	8. Transport Canada File No. D1460-145-11
9. Performing Organization Name and Address MMS Man-Machine Systems Consultants Inc. 288 Erskine Avenue Toronto, Ontario M4P 1Z4	10. DSS File No.
	11. DSS or Transport Canada Contract No. TDC 4792
12. Sponsoring Agency Name and Address Transportation Development Centre 1000 Sherbrooke Street West Suite 2421 Montreal, Quebec H3A 2R3	13. Type of Report and Period Covered Final Report 22 September-21 December 1982
	14. Sponsoring Agency Code TDC 4792
15. Supplementary Notes	16. TDC Project Officer Dr. R. Heron

17. Abstract

This report discusses a project whose general objective was related to the possible development of a ship-handling simulator with a view to improving Canadian capability in year-round arctic navigation. This project entailed visits to four European ship-handling simulators to (a) obtain preliminary information concerning the sensory fidelity needed to carry out both research and training in ice-related navigation with a simulator; (b) assess the utility and success of simulators for research and training; (c) examine the experimental designs used in simulator research; and, (d) develop a protocol for obtaining complete information on future visits to other simulator sites. The installations visited were: (1) the model board simulator at the Institute for Perception, TNO, Soesterberg, Netherlands; (2) the point light source simulator, with engine room simulation, at the Institute for Mechanical Constructions, TNO, Delft, Netherlands; (3) the point light source simulator at the Maritime Research Institute, Wageningen, Netherlands; and, (4) the computer-generated imagery simulator at Cardiff, Wales, operated by the University of Wales Institute of Science and Technology (CASSIM). An important recommendation among several arising from the obtained information is that the visual component of an ice-related ship-handling simulator will require computer-generated imagery to simulate the essential aspects of ice as well as the movement of ships through ice.

18. Key Words	19. Distribution Statement
Ships, ice, navigation, simulators, ergonomics (human factors engineering) research design	Limited number of copies available at TDC

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	15	

TDC/CDT 79-006

FORMULE DE DOCUMENTATION POUR RAPPORT

1. Nº du rapport Transports Canada	2. Nº de l'étude — CDT	3. Nº de catalogue du destinataire
4238E	4792	

4. Titre et sous-titre	5. Date du rapport
"Report on Four Visits to Marine Ship - Handling Simulators in the Netherlands and the U.K."	décembre 1982
	6. Nº du rapport de l'organisme exécutant: MMS-4

7. Auteur(s)	8. Nº de dossier Transports Canada
John W. Senders	D1460-145-11

9. Nom et adresse de l'organisme exécutant	10. Nº de dossier — ASC
MMS Man-Machine Systems Consultants Inc. 288 Erskine Avenue Toronto, Ontario M4P 1Z4	11. Nº de contrat — ASC ou Transports Canada: TDC 4792

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de développement des transports 1000 ouest, rue Sherbrooke Suite 2421 Montréal, Québec H3A 2R3	Rapport final 22 septembre-21 décembre 1982 14. Code de l'organisme parrain: TDC 4792

15. Remarques additionnelles	16. Agent de projet — CDT
	Dr. R. Heron

17. Résumé

Ce rapport traite du projet d'étude d'un simulateur de manoeuvres dans les glaces qui ouvrirait aux navires canadiens la perspective d'une navigation dans les eaux arctiques, l'année durant. Ce projet a nécessité la visite de quatre installations européennes dans le but: a) d'acquérir de première main des renseignements sur le degré de fidélité à atteindre dans la représentation des données relatives à la navigation dans les glaces; b) d'évaluer l'utilité et l'efficacité des simulateurs, dans l'optique de la recherche et de la formation; c) d'examiner les modèles expérimentaux appliqués à la recherche dans le domaine considéré et d) d'élaborer un protocole d'entente pour l'obtention de renseignements scientifiques complets, à l'occasion de visite ultérieure à d'autres installations du genre. Les installations visitées ont été les suivantes: 1) le simulateur à maquettes, à l'Institut de recherches sur la perception, TNO Soesterberg, Pays-Bas; 2) le simulateur à ombres portées, complété d'une figuration de la salle des machines, à l'Institut des constructions mécaniques, TNO, Delft, Pays-Bas; 3) le simulateur à ombres portées, à l'Institut des recherches maritimes, Wageningen, Pays-Bas; et 4) le générateur d'images produites par ordinateur, à Cardiff, Pays de Galles, et exploité par l'Institut des sciences et des techniques, University of Wales. Une des recommandations suscitées par les informations obtenues a été celle de doter le simulateur considéré d'un système de visualisation alimenté en images produites par ordinateur, dans le but de représenter les caractéristiques essentielles des glaces, ainsi que les mouvements du navire qui les franchit.

18. Mots-clés	19. Diffusion
Navires, glaces, navigation, simulateur, economie (relations homme-machine) recherche	Le CDT dispose d'un nombre limité d'exemplaires

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Non-classifié	Non-classifié	15	

CDT TDC 79-005

Acknowledgements

The author acknowledges the kind assistance of Mr. H. Schuffel of the Institute for Perception, TNO, Soesterberg, Netherlands; Mr. D. W. Jaspers, Mr. W. Veldhuyzen and Mr. W. DeJoode of the Institute for Mechanical Constructions, TNO, Delft, Netherlands; Mr. Meurs and Mr. Elzinga of the Maritime Research Institute, Wageningen, Netherlands; and Professor A. D. Couper, Dr. I. R. MacCallum, Mr. R. Matthews and Dr. Duncan of the University of Wales Institute of Science and Technology at Cardiff, U. K.

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REPORT ON FOUR VISITS TO MARINE SHIP-HANDLING SIMULATORS IN THE NETHERLANDS AND THE U.K.

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1. INTRODUCTION

In accord with the instructions of the service contract between Man-Machine Systems and Transportation Development Centre (Contract - 4792, dated 22 September 22, 1982), Professor J. Senders visited three ship-handling simulators in the Netherlands and one ship-handling simulator in the United Kingdom, and interviewed senior personnel in these four establishments on matters relating to the use of ship-handling simulators for research and training in ice covered waters and in icebreaking operations. The report of these visits is contained in this document.

I visited in succession the ship-handling simulator at the Dutch Institute for Applied Research in Science (TNO) at Soesterberg; the Dutch Research Institute, TNO, for Mechanical Constructions at Delft; and the Maritime Research Institute of the Netherlands at Wageningen. The final visit was made to the Cardiff Ship Simulator, CASSIM, at the University of Wales Institute of Science and Technology in Cardiff. The interviews were tape recorded. The approach chosen in each of the four was different in an effort to see which method was most productive of useful information. A protocol for future site visits, developed on the basis of these interviews, is provided in Section 7.

2. SOESTERBERG

At the Institute for Perception, TNO, at Soesterberg I interviewed Mr. Herke Schuffel, Director of Ship Manouvering Simulator Facility. The Institute for Perception is an applied research institution with an excellent reputation for both basic and applied research involving man-machine interaction.

2.1 Simulations

The visual simulation uses a model board technique. The board is a small scale replica of the geography and construction of the harbour or gaming area. A television camera mounted above the board can be traversed in x and y and rotated in order to provide different views of the visual display. The camera is driven by the computer which translates the commands of engine and helm through ship dynamics into resultant movement. The television image is then projected onto the screen outside the windows of the bridge of the simulated vessel.

2.2 Experimental designs and data analysis

Mr. Schuffel's research approach to ship-handling involves classical experimental designs. The general problem is to determine whether condition A is better than condition B. Variables involving position and movement of the vessel are measured. No human performance measures are taken. Multivariate designs are used with sixty-four trials in a two by two matrix, sixteen trials per cell. For example, there might be two ship-handling conditions, (1) within a harbour and (2) manoeuvring on the open sea, and two conditions of equipment, (1) standard and (2) some innovative equipment. Sixteen pairs of masters and mates would participate in all four treatment combinations. Details of the experimental designs and analyses are found in the papers cited in the bibliography at the end of this report.

During simulation trials, the position and movement of the ship are recorded by the computer and compared with an optimized ship movement trajectory. The deviation in each of a succession of blocks over the duration of a run forms the data base for each trial. Thus there might, in the course of a one hour trial, be twenty blocks; each block would have an integrated error reading associated with it. It would therefore be possible to do an analysis of variance for each block as well as for the total error of the run.

Each trial on the simulated large vessels would run from one to one and a half hours. An entire experiment of this size would involve six weeks of full-time operation. The cost of experimental research is 250 Dutch guilders operating cost per hour. The overall cost including the cost of the subjects is approximately 1000 guilders per hour. Thus, the sixty four trial experiment mentioned would cost, including preparation time and lost time, approximately 130000 guilders or 65000 Canadian dollars. This includes amortization of the capital cost of the equipment.

2.3 Validation and restrictions

Validation of ship-handling simulators is considered to be adequately covered by informally asking barge captains and other marine personnel on the simulator how faithful simulation is and how well it compares with reality. Neither sound nor motion is incorporated since it is assumed that visual fidelity is most important for training and research (this claim has not been tested at Soesterberg). Mr. Schuffel was not able to estimate the relative benefit of motion (he informed me that two simulators with moving bases existed, one at the Maritime Institute for Technology and Graduate Studies (MITAGS) in Baltimore, Maryland, and the other at the Hamburg Simulator, Hamburg Polytechnic Institute School of Navigation). In his opinion the simulators are very successful for both research and training and there are no problems of acceptance by the marine community. No work related to ice covered waters has been undertaken by this facility; nor would they be able to do this unless suitable equations of motion were provided them to be programmed into the computer.

2.4 Additional findings

Much additional information was gained in the visit to Soesterberg where I learned of the existence of the International Marine Simulator Forum IMSF. This organization is recently formed, and a copy of the constitution and a list of members is attached (a list of all attachments to this report is found in Appendix A). Associate membership in this organization would be valuable for the Transportation Development Centre. In addition, I was made aware of the existence of the proceedings of a number of international conferences, in particular, the proceedings of the First International Conference on Human Factors in the Design and Operation of Ships, which was held in Gothenberg, Sweden, in February 1977. Attached is the title page of the proceedings and a copy of the table of contents. The Second International Conference on Human Factors at Sea, presumably a continuation of the 1977 conference despite the change in title, was held at Plymouth, United Kingdom in 1981. This latter conference was entitled Ergosea '81, and this presumably will be the model for future conferences of the same sort. Also enclosed is the cover and table of contents of the proceedings of the First International Conference on Marine Simulation, MARSIM '78, held at Southampton, England, in September 1978. Presumably later MARSIMs have been held; whether they are annual events I do not know, however there was a MARSIM '81. There further was a Ship Control Systems Symposium, the fifth conference, held at the David W. Taylor Naval Ship Research and Development Centre at Annapolis, Maryland on October 30th, 1978. The first such conference was held in 1966. The proceedings of these conferences would be most useful; there is reference to arctic problems in them. Reference was also made, although with some uncertainty, to a report by a Captain Hegelstrum or Hegelstum (Mr. Schuffel was unsure of the name) of Bore Steamlines, a Norwegian-Swedish operation regarding ice navigation problems. Attached as well is a copy of the bibliography of reports which have been issued by the Soesterberg Simulator Group, and copies of those reports written by Herke Schuffel as well.

In summary, the ship-handling simulator at the Institute for Perception at Soesterberg is used predominantly for well-constructed research designs of the classical sort, analysed by analysis of variance or multivariate regression techniques. Some training is also done, but this is of secondary importance, since the principal mission of the institution is research. There is no special competence or experience in arctic navigation or icebreaking training and research.

3. DELFT

The second visit was to the Institute for Mechanical Constructions TNO in Delft. The principal director of the simulator is Mr. B. W. Jaspers. He was accompanied by Mr. W. Veldhuyzen and Mr. W. DeJoode.

3.1 Simulations

The simulation is based on the point light source technique. A scale model of the harbour is built with three-dimensional miniatures of all the objects near which or past which the vessel may travel, plus flat plate representations of distant objects on the shore. A point source of light shines through these models from a point very close to the surface of the simulated sea. The shadows cast are then a faithful reproduction of what an observer would see if his eye were where the point of light is. These shadows are cast on a screen which is then observed from the other side by the trainee. The claim was made that a model for a new harbour area could be constructed in about one man month (although there was some dispute about this at Wageningen, where it was felt that it would take longer). The system can be used in the following way: the point of light is fixed, the model is on an x-y traversing and rotating table. These three degrees of freedom are driven by the output of the vessel's dynamics as simulated on the computer, so that if the vessel rotates to the right, the shadow graph scene rotates to the left from the observer's point of view thus creating the illusion of the vessel moving to the right. As the vessel, i.e. the point light source, moves closer to the shadow casters, that is, to the profiles and models, the shadows they cast become larger in direct proportion to the change in distance. Thus the observer in the Master's position on the bridge sees a faithful reproduction of the outline of what he would see if his eye were in fact at the light source.

This simulator, unlike the others, has a complete simulation of the engine room, so that, either independently or simultaneously, the function of the engineer can be trained or investigated. The simulation as shown in the accompanying brochure is a comprehensive computer-driven identical version of the engine room. A wide variety of emergency conditions and failures can be simulated, and the response of the engineer recorded. This is a most impressive function and makes possible the study of the interaction of helm and engine, which may be vital for the investigation of icebreaker operations. The other simulators have a dummy engine room in which the functions are simulated by a person who inserts parameters in accord with commands from the bridge.

In addition, tugs can be inserted, which appear as forces attached to the simulated vessel in the computer. Appropriate delays and tug response characteristics are simulated by the person handling that part of the training exercise. This feature was found in all of the simulators that were visited.

3.2 Experimental designs and data analysis

The mission of the simulator is predominantly training, therefore no experimental designs were used and no statistical analysis is involved. Essentially, a group of mariners uses the simulator to engage in seven to nine manoeuvres for each of the men, the others acting as observers, helm, plotter, radar man and so on so that each person actually performs a number of times and then observes a great many more times. The trials may last anywhere from 15 minutes to two hours. Basically, the data recorded are the track, that is to say the position of the wheel house on the chart. This is different from Wageningen, as will be seen where they record the centre of mass of the vessel. (This difference reflects an emphasis on operator performance at Delft as opposed to ship performance at Wageningen.) In addition, rudder angle, rate of turn, lateral velocity, RPM's, speed through the water, and heading are all recorded as functions of time and position on the track. Engine orders from the bridge to the engine room are also recorded. No effort is made at analysis of the data, in so far as I could determine. Essentially, when the performance is within some reasonable criteria, the training is presumed to be complete. Validation is by consensus of the master mariners familiar with these waters. The combined operating and capital cost of the equipment on an eight hour day is 1800 Dutch guilders, or about 900 Canadian dollars.

3.3 Additional findings

The people at this Institution expressed an interest in working with ice, although they agreed that the effects of shock and motion were probably vital to the examination of the man-machine interaction in icebreaking operations (this opinion has not been tested directly by research at Delft). Although this group had not done work on ice navigation, they indicated an interest and a willingness to participate in the costs of such studies. Data, of course, would have to be furnished as to the dynamics of the vessel in ice covered waters. They referred me to studies which have been done in Wageningen using paraffin on tanks as a way of simulating floating ice. No details were available on the outcome of these studies.

Shock and motion were believed to be important for the investigation of ship-handling performance in ice because operator reaction times to kinesthetic and vestibular inputs are shorter than reaction times to visual inputs. This difference in operator responsiveness may be critical for manoeuvring in ice.

In summary, the principal virtue of the simulator at Delft is its magnificent engine simulation. The quality of the shadow projection is very good, but like the model board television scheme it does not permit the introduction of moving traffic or objects such as icebergs. The machine is used for training almost to the total exclusion of research, although there is a recognition that research could be done on it. The engine room would lend itself admirably to research programmes.

4. WAGENINGEN

The third visit in the Netherlands was to the Maritime Research Institute at Wageningen, a facility that is used partly for training and partly for research. I spoke at Wageningen with Mr. Meurs, who is a master mariner and a Mr. Elzinga, who is the project manager for ship-handling at the Maritime Research Institute.

4.1 Simulations

The Institute has large water tanks for examining the effects of waves and for towing research. These facilities are for studies of ship performance only and do not involve operator research or training. In addition, it has a point of light bridge simulator like the one at Delft. The engine room is a simulated function rather than a simulated space, so that tugs and engine operations are dialed in by an operator who receives the commands from the bridge. The projector is essentialy the same as the one at Delft, and so is subject to the same limitations.

4.2 Experimental designs and data analysis

They take essentially the same measures as does Delft, with the exception that the centre of mass of the vessel rather than the wheelhouse is considered to be the position of the vessel. Heading, rudder angle, rate of turn, RPM, current, tide, wind, latitude, and lateral and longitudinal motion are taken at each cross section of the channel so that a great many samples are possible, along the desired track. Verbal communications are also recorded.

Analysis of variance is performed on deviation data from track. Experiments involving as many as thirty-six cells are performed with forty five minutes per cell; the experiments take one to two weeks, with some consuming as many as 140 hours. The all-up cost is 1200 guilders or about 600 Canadian dollars per hour including capital cost. A full-time-equivalent cadre of fourteen people mans the simulator and is presumably the major cost item.

4.3 Additional findings

There is generally good acceptance by senior mariners, particularly after brief exposure to the system. Movement and system dynamics are considered to be the most important aspects of simulation fidelity. They also called my attention to MITAGS in Baltimore which has a moving base simulator. In general their philosophy is that they do not use landmarks but instead: beacons, buoys and things which are shown on the navigational charts as being immediately adjacent to the sea or in the sea. The reason for this is that they feel that navigation cues are more reliable than landmarks which may change without advance notice (this opinion has not been tested by research at Wageningen). Again, this simulator is used largely for training, but does have some research capability and experience. The machine is essentially the same as the machine at Delft, with the exception that the machine at Delft has an extensive engine room simulation.

5. CASSIM

The fourth visit was to the University of Wales Institute of Science and Technology Simulator at Cardiff. Here, we find a totally different atmosphere, and a totally different technology. The atmosphere is one of research. Professor Couper is the Director of CASSIM-Cardiff and head of the Department of Maritime Studies at UWIST. Ian MacCallum is the simulator manager; Robert Matthews is a senior staff member. Dr. Duncan, a Human Factors Psychologist, is on staff and engages actively in research programmes. The simulator has been in commission only a short time, so there is no extensive bibliography of reports to be considered. However, if a collaborative effort were to be undertaken to do icebreaker research, it is at this institution, of the four I visited, that I would recommend the principal effort be applied.

5.1 Simulations

The facility at UWIST Cardiff is the only one of the four visited which uses a comptuer generated image system. The system was developed and constructed by Marconi Limited in the U.K. Because of cost considerations only three projectors were used, so the lateral view is currently limited. Additional projectors may be obtained when funds become available. Because of the nature of the image generating system, it is possible to introduce moving elements and variable elements, so that icebreaking operation could, from the visual point of view be well simulated. That is to say, if the ice were impacted by the vessel, its new structure could be computer-synthesized and presented visually. This simulator has a small amount of vibration and motion in the platform designed to give the mariner a sense of shaft behaviour. The UWIST staff believe that this is an important part of the process of control; it allows the operator to directly monitor engine performance. As in all the other simulators, the bridge is realistic and the displayed images are effective. The display has colour and adequate brightness, so that visibilities of perhaps four to five miles can be adequately simulated. There is no engine room: The engine functions, like those at Soesterberg and Wageningen, are simulated by an operator at a console. Generally speaking the image quality of this computer-generated image system was as good as that of the television system. Both of these were superior to the point of light simulations.

My impression upon having seen four different simulators is that the CGI is the only suitable way to deal with the human aspect of the ice problem. Naturally, all conceivable variables can be extracted from the computer. The vessel dynamics are embedded in the computer, along with the geography of the scene, and the relevant data can be stored or printed out as needed. In a sense, there is no limit to the data recording or data analysis possibilities in systems of this sort.

The computer generated image system requires approximately three man-months of programming to prepare a new harbour. This was the case, for example, for the simulation of Ventulu Harbour in the far east, where masters were trained on the CASSIM simulator using imagery that was developed for this purpose. Mr. Ian Ringvers did the visuals, with the assistance of programmers.

5.2 Additional findings

The cost of operation is approximately 120 pounds per hour or about $250 Canadian, not including amortization of equipment capital cost. Direct construction and installation costs were approximately 1.5 million pounds Sterling. About half of this money came from outside the University: Marconi made a contribution of approximately 500,000 pounds, and another 250,000 pounds came from other external sources. It took about three years from the start of the contract to the completion of acceptance tests.

With regard to the general question of the importance of fidelity, they felt that dynamics are extremely important to the mariner; that there needs to be research on the value of optical fidelity; that sounds and vibration are important (their claims regarding dynamics, sound, and vibration have not been tested at CASSIM). They also commented, on the basis of informal observations, that the physiological response of the mariner to both real and simulated harbour entry was the same. This is at least some testimony to the adequacy of the simulation.

The CASSIM group has had continuing extensive contact with a variety of Canadian agencies: Dome Petroleum, Arctec Canada, Canadian Coast Guard, Dalhousie Ocean Studies Group, the Bedford Institute and Mr. Hillier of the Canadian High Commision in the U.K. They have had discussions with Mr. Ray Gibson at the Ontario Ministry of Industry and Tourism with regard to the possibility of using simulation for the study of arctic navigation. The Canadian Pacific Coast's Pilots Association came to CASSIM, as well as to Southampton, Warsash, and the manned model centre at Grenoble, in an effort to see which system would be most suitable for training of pilots. CASSIM is also engaged in a transfer of training study for the Royal Navy on frigates using two matched groups, one on the vessel itself, one on the simulator. The study is not completed, so the results are not yet available.

6. RECOMMENDED ACTIONS

Simulation of the visual aspects of arctic ship-handling demands a faithful representation of (1) differences in types of ice (e.g., first year, multi-year, snow covered), (2) ice effects (e.g., pressure ridges, moving ice) and (3) changes in the characteristics of ice on impact. Model boards and point of light visual systems are not sufficiently flexible to simulate all of these aspects of ice. The computer

generated image provides the ideal mechanism for presenting differences in types of ice, ice effects and the characteristics of the ice both before and after the vessel has impacted it.

Professor Couper of CASSIM wrote to me shortly after my return. He specifically suggested a joint pilot or feasibility project between Canada and some simulator research and training group. I would strongly recommend that such a joint program be considered. I felt that my meeting with Professor Couper, and my previous acquaintance with Doctor Duncan, the Human Factors Psychologist on staff there, would make it possible to organize research which would answer many of the questions that Transportation Development Centre currently has.

Admittedly, we have not yet explored the other simulators, and before committing oneself completely to a programme with UWIST, attractive as it is, it would be desirable to visit CAORF and Gothenberg (CGI displays), the MITAGS simulator in Baltimore with a moving base, and the CGI display simulator in Hamburg Germany, which also has a moving base.

It would be of interest to compare identical programmes done on the same model at UWIST with its excellent visual fidelity and shaft vibration capability with either Hamburg or Baltimore which possess the moving platform. Whether these moving platforms would have the power necessary to reproduce the shock of impact in ice in a realistic way can only be determined by further investigation.

I suspect that it is uneconomic to do a world-wide survey of simulators and recommend instead that future site visits concentrate on facilities with either CGI displays and/or moving platforms. It would also be extremely worthwhile for Transportation Development Centre to enrol in an associate membership in the International Marine Simulator Forum, and attend the meetings of MARSIM, ERGOSEA and IMSF in order to establish contact on a more permanent basis with the persons who operate and direct these other simulators.

It is unfortunate that the simulator at UWIST does not have a complete engine room simulation. I suspect that in all marine work, but especially arctic navigation and icebreaker operations, the coordination between bridge and engine room could be of the utmost importance for successful work. A simulated engine room never makes an error, nor does it have an emotional response or a difference of opinion. It would probably be desirable at some point, perhaps on the Delft simulator, to run a check study for some typical manoeuvre to see whether the existence of an engineer in an engine room makes a significant contribution to the validity and value of the results of research.

7. PROTOCOL FOR FUTURE INSTALLATION VISITS *

Information will gathered on as many as possible of the following points.

7.1 Ownership and Operation

a. Identification of ownership and operating groups
b. Other groups with privileges
c. Establishment of scheduling priorities
d. Number and training of personnel employed
e. Training and qualifications of manager of the facility
f. Balance between research and training use of the facility
g. Administrative structures for research and training
h. Is there a development program to accommodate the gradual expansion of the facility and/or to allow for state of the art changes in hardware and software?

7.2 Capital and Operating Costs

a. Original capital cost in year of completion
b. Amortization of capital cost
c. Financing arrangements for ongoing operation and routine maintenance
d. Financing arrangements for improvements and extraordinary maintenance
e. Breakdown of operating costs, e.g., personnel, maintenance, overhead
f. Costs of preventive and corrective maintenance contracts

7.3 Equipment, Maintenance and Reliability

a. Manufacturers of major components and year of acquisition
b. Reliability of entire system and various subsystems in terms of hours of down time, including time spent on routine maintenance
c. Availability of replacement parts
d. Quality of vendor service

7.4 Computer Facility

a. Computer configuration(s)
b. Real-time response capabilities
c. Backup facilities
d. Separate facilities for data analysis and/or administrative computing?

7.5 Bridge Layout

a. Size
b. Flexibility

7.6 Visual Simulation

a. Type of system
b. Type of projector
c. Field of view per projector, horizontal and vertical
d. Type of projection, e.g., rear
e. Radius of screen
f. Screen resolution, illumination level, alignment
g. Number of colours
h. Diagonal edge smoothing
i. Sea texture, distance effects
j. Sky texture
k. Land texture
l. Types and characteristics of ice, e.g., first year, multi year, snow covered
m. Ice effects, e.g., pressure ridges, icebergs, moving ice
n. Ice texture on impact
o. Shadows, lights, direction of illumination
p. Traffic vessels
q. Land and seamarks
r. Data base characteristics

7.7 Dynamic Simulation

a. Propulsion, steering, and thruster dynamics
b. Hydrodynamics
c. Traffic vessel characteristics
d. Environmental effects
e. Ice effects
f. Navigational equipment, e.g., radar, Loran C, echo sounder

7.8 Motion Simulation

a. Fixed vs. moving base
b. Engine vibration
c. Degrees of freedom of platform motion
d. Platform dynamics
e. Simulation of impact on ramming
f. Motion simulation of continuous mode operation in ice
g. Coordination of motion with dynamic, visual and acoustic simulations

7.9 Acoustic Simulation

a. Acoustic effects, ice noise
b. Coordination with motion, dynamic and visual simulations

7.10 Communications Simulation

a. Ship-shore, intra-ship, inter-ship

7.11 Engine Room Simulation

a. Simulated function or simulated space
b. Operational characteristics

7.12 System Operation and Monitoring

a. Basic operating modes
b. Experimental/instructor intervention for malfunctions, environment, traffic vessels, etc.
c. Statistical routines
d. Experimental designs
e. Monitoring station characteristics

7.13 Research Program

a. Active research interests and approach
b. Operator and ship characteristics recorded
c. Data sampling rates
d. Costs of research
e. Validation studies

7.14 Human Performance Considerations

a. Recording and analysis of communications
b. Recording and analysis of operator control actions
c. Video recording and analysis of bridge activities and interactions
d. Manipulations of event density

* Protocol prepared by D. J. Ostry and D. C. Donderi

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